Intelligent Modelling of the air Transport Network

‘Impact of innovative prioritization strategies on delay patterns’

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The Problem

- Limited Availability of the air transportation system resources
  - On Ground: Limited capacity of an airport (runways, gates, etc)
  - On the air: Capacity of the sectors is not infinite.
- According Eurocontrol forecast between 2008 and 2030 an average annual growth between 2.3 and 3.5% will occur in Europe, up to almost duplicate the traffic.
- The airport capacity will increase by 41% in the same period. Demand will exceed capacity in 2030 by almost 7 million flights.
- The capacity is further reduced when an occasional event occurs (either expected or unexpected).
- When an imbalance happens, a regulation is imposed (either in ground or in the air) and the flights are prioritised on a First Come First Served basis.
Objectives

NEWO stands for “emerging NEtwork-Wide effects of inventive Operational approaches in ATM”.

Objectives:

1. Explore potential network wide benefits or adverse effects of the application of local approaches

2. Further develop and explore the potential of Network Wide innovative modelling and simulation techniques
### Project Methodology

#### Exploring Innovative Operational Approaches

<table>
<thead>
<tr>
<th>Workshop Results</th>
<th>Workshop for</th>
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<tbody>
<tr>
<td><strong>Most Promising Criteria</strong></td>
<td><strong>Experimental Plan</strong></td>
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<td>Priority to flights to airports with higher/lower number of outgoing flights</td>
<td>ATM NEMMO Modelling approach</td>
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<tr>
<td>Priority to flights to more/less congested airports</td>
<td>Simulation Runs</td>
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<td>Priority to hub &amp; spoke airlines</td>
<td>Results analysis</td>
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<td>Priority to last flight of the day (for the aircraft)</td>
<td>Most Promising Criteria</td>
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<td>Priority to flights with more subsequent flight legs</td>
<td>Priority to flights with greater/smaller turnaround buffer time at next airport</td>
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<td>Priority to flights with greater/smaller turnaround buffer time at next airport</td>
<td>Priority on random basis</td>
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<tr>
<td>Priority to flights connecting different communities</td>
<td>Priority to flights to less central destination</td>
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<tr>
<td>Priority to Most Capable Flights (Most Capable Best Served)</td>
<td>Conclusions and Strategic Recommendations</td>
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### Conclusions and Strategic Recommendations
Experimental Plan

- The network-wide effects of the different prioritization criteria are analysed through **Modelling scenarios** (5)

- A **set of Exercises** is assigned to each Modelling Scenario;

- A number of runs is conducted in each exercise to assure that is statistically significant

- For the results analysis different **Performance Indicators (PI)** are monitored per Exercise

<table>
<thead>
<tr>
<th>KPA</th>
<th>Performance indicator (PI) ID</th>
<th>Local</th>
<th>Global</th>
<th>PI Name (Unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>EFF.ECAC.PI1</td>
<td>X</td>
<td>X</td>
<td>Percentage of flights departing on time</td>
</tr>
<tr>
<td></td>
<td>EFF.ECAC.PI2</td>
<td>X</td>
<td>X</td>
<td>Average Departure delay per flight</td>
</tr>
<tr>
<td>Predictability</td>
<td>PRED.ECAC.PI2</td>
<td>X</td>
<td>X</td>
<td>Average departure delay of departure flights</td>
</tr>
</tbody>
</table>
Scenarios

- Scenario 1 “Impact of the prioritization criteria on the network stability”
  - All Criteria compared against FCFS
  - External Disturbances

- Scenario 2 “Relation between network stability and equity (α calibration and priority points)”
  - Designed to investigate how giving priority to airlines interests provides the best impact in terms of network stability:

```
Flight priority in two parts: P_f = α(airlines criteria) + (1-α)(network criteria)
```

- Scenario 3 “Airlines interests as a black box”

- Scenario 4 “Network Critical Load Analysis”

- Scenario 5 MCBS vs FCFS
Complexity Science applied to the study of the Air Transport Network

Air Transport Network approach…

- Airports are nodes with symmetric relationships
- Elements travelling between nodes are flights or aircrafts;
- Weight of the links is given by the number of flights connecting two airports;

Air Transport Network’s properties

- Queuing and congestion generation;
- Delay propagation;
- Small World property;
- Scale-free or power-law degree distribution:
- Community Structures (Hubs)
The Approach: ATM-NEMMO

Mesoscopic model

- First European airports: 133 nodes handling 90% of the traffic
- 5 nodes called AREA (from 1 to 5) collecting departures from/ arrivals to airports outside ECAC area grouped by geographical areas;
- OTHER: 1 node representing the flows of secondary airports.
- SAMPLE: 1 day of flown traffic in Europe from April 2012 (27658 Flights).

Elements travelling between two nodes are aircraft
The Approach: ATM-NEMMO

- Links: the interaction between elements facilitates the propagation of the delays.

- The different type of delays are modelled similarly in the tool: target times are updated (i.e.: Estimated Take Off Time –Delayed Take Of Time);
The Approach: ATM-NEMMO

Network is subject to internal and external disturbances:

- **Internal Disturbances**
  - related to the variability associated to air traffic processes or elements and are inherent to the air traffic network

- **External Disturbances**
  - Produced by elements not part of the Air Traffic Network, unexpected events leading to abnormal conditions

Uncertainty = stochastic variable following a probability distribution

Modelled as Capacity shortfalls at airports
Simulation Results

Impact of prioritization criteria on the network stability (SCENARIO 1)

FACTS:
- More than 30 exercises conducted (over 6000 simulation runs)
- Results analysed both at global and local level.
- All the criteria analysed one by one and vs FCFS

Some Examples …

Percentage of flights departing on time

PI1 Percentage of flights departing on time

1 hour time intervals
Simulation Results

Impact of prioritization criteria on the network stability (SCENARIO 1)

- Examples of the values of Performance Indicators at network level:

![Graph showing average departure delay per flight for different prioritization criteria.

- Delay minutes

- PI2 Average departure delay per flight

- 1 hour time intervals

- FCFS
- CRITERION1a
- CRITERION1b
- CRITERION7

- EX2-G1A-FCFS
- EX8-G1A-Ci-1
- EX9-G1A-Ci-2
- EX25-G1A-Cviii

- SESAR INNOVATION DAYS 2013

- 28/11/2013
### Simulation Results

#### Impact of prioritization criteria on the network stability (SCENARIO 1)

<table>
<thead>
<tr>
<th>Departure Airport</th>
<th>ICAO Code</th>
<th>% Flights departing on time</th>
<th>Av. Delay per flight (FCFS)</th>
<th>% Flights departing on time</th>
<th>Av. Delay per flight (CRITERION 1a)</th>
<th>% Flights departing on time</th>
<th>Av. Delay per flight (CRITERION 1b)</th>
<th>% Flights departing on time</th>
<th>Av. Delay per flight (CRITERION 7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MADRID</td>
<td>LEMD</td>
<td>80.35%</td>
<td>6.93</td>
<td>32.08</td>
<td>74.98%</td>
<td>8.11</td>
<td>30.69</td>
<td>77.40%</td>
<td>7.44</td>
</tr>
<tr>
<td>LISBON</td>
<td>LPPT</td>
<td>57.33%</td>
<td>15.13</td>
<td>21.59</td>
<td>85.70%</td>
<td>6.34</td>
<td>20.39</td>
<td>49.56%</td>
<td>8.16</td>
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<tr>
<td>PALMA DE</td>
<td>LPM</td>
<td>60.03%</td>
<td>11.93</td>
<td>47.92</td>
<td>57.51%</td>
<td>7.26</td>
<td>24.16</td>
<td>57.58%</td>
<td>12.19</td>
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<tr>
<td>NAPLES</td>
<td>LEPA</td>
<td>56.44%</td>
<td>5.11</td>
<td>22.28</td>
<td>83.16%</td>
<td>6.48</td>
<td>20.04</td>
<td>51.90%</td>
<td>6.40</td>
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<td>LONDON WUXT</td>
<td>EGW</td>
<td>73.86%</td>
<td>7.06</td>
<td>30.64</td>
<td>75.88%</td>
<td>7.82</td>
<td>28.64</td>
<td>77.78%</td>
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<td>ALICANTE</td>
<td>LEAL</td>
<td>54.67%</td>
<td>5.21</td>
<td>15.15</td>
<td>60.89%</td>
<td>6.21</td>
<td>17.10</td>
<td>64.48%</td>
<td>4.91</td>
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<tr>
<td>FRANKFURT</td>
<td>EDDF</td>
<td>73.03%</td>
<td>6.58</td>
<td>31.18</td>
<td>66.89%</td>
<td>7.51</td>
<td>25.61</td>
<td>66.88%</td>
<td>7.49</td>
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<tr>
<td>MALAGA</td>
<td>LEIG</td>
<td>63.51%</td>
<td>5.69</td>
<td>18.65</td>
<td>58.21%</td>
<td>6.74</td>
<td>20.04</td>
<td>59.19%</td>
<td>6.29</td>
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<tr>
<td>ROME</td>
<td>LIRI</td>
<td>56.67%</td>
<td>5.88</td>
<td>25.68</td>
<td>68.83%</td>
<td>6.04</td>
<td>24.12</td>
<td>67.95%</td>
<td>6.46</td>
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<tr>
<td>LONDON GATwick</td>
<td>EGKK</td>
<td>56.52%</td>
<td>5.20</td>
<td>23.09</td>
<td>52.53%</td>
<td>6.08</td>
<td>21.97</td>
<td>52.66%</td>
<td>5.99</td>
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<tr>
<td>LONDON HEATHROW</td>
<td>EGLW</td>
<td>73.76%</td>
<td>6.73</td>
<td>32.47</td>
<td>71.78%</td>
<td>7.36</td>
<td>30.47</td>
<td>72.88%</td>
<td>7.36</td>
</tr>
<tr>
<td>BARCELONA ELS</td>
<td>LEBL</td>
<td>73.38%</td>
<td>7.09</td>
<td>31.39</td>
<td>70.38%</td>
<td>8.04</td>
<td>29.08</td>
<td>70.03%</td>
<td>8.36</td>
</tr>
<tr>
<td>AMSTERDAM</td>
<td>EHAM</td>
<td>73.49%</td>
<td>7.26</td>
<td>30.59</td>
<td>70.92%</td>
<td>8.12</td>
<td>27.99</td>
<td>66.89%</td>
<td>8.46</td>
</tr>
<tr>
<td>SCHRIFHOL</td>
<td>EHAP</td>
<td>56.69%</td>
<td>5.08</td>
<td>16.50</td>
<td>49.71%</td>
<td>6.84</td>
<td>17.86</td>
<td>48.98%</td>
<td>6.90</td>
</tr>
<tr>
<td>BUDAPEST</td>
<td>LMKF</td>
<td>73.90%</td>
<td>9.72</td>
<td>40.41</td>
<td>69.19%</td>
<td>8.59</td>
<td>28.41</td>
<td>68.41%</td>
<td>9.16</td>
</tr>
<tr>
<td>MILAN</td>
<td>LMML</td>
<td>73.03%</td>
<td>6.69</td>
<td>23.32</td>
<td>66.88%</td>
<td>6.68</td>
<td>23.84</td>
<td>66.19%</td>
<td>8.79</td>
</tr>
<tr>
<td>NICE</td>
<td>LMNN</td>
<td>70.03%</td>
<td>6.18</td>
<td>24.69</td>
<td>68.06%</td>
<td>6.38</td>
<td>24.41</td>
<td>62.50%</td>
<td>6.87</td>
</tr>
<tr>
<td>PARIS CDLY</td>
<td>LFPG</td>
<td>57.32%</td>
<td>4.92</td>
<td>23.78</td>
<td>53.03%</td>
<td>5.84</td>
<td>22.72</td>
<td>56.41%</td>
<td>4.89</td>
</tr>
<tr>
<td>WARSAW</td>
<td>LFMA</td>
<td>67.11%</td>
<td>5.72</td>
<td>23.69</td>
<td>62.77%</td>
<td>6.70</td>
<td>23.20</td>
<td>64.38%</td>
<td>6.27</td>
</tr>
</tbody>
</table>

**Example of the values of Performance Indicators at local level (at EHAM airport):**

- **Percentage of flights departing on time:**
  - FCFS: 80.35%
  - CRITERION 1a: 74.98%
  - CRITERION 1b: 68.89%
  - CRITERION 7: 70.92%

- **Av. Delay per flight (1 hour time intervals):**
  - FCFS: 6.93
  - CRITERION 1a: 8.11
  - CRITERION 1b: 6.21
  - CRITERION 7: 8.59

**Graphical results for Percentage of Flights Departing on Time (EHAM):**

- **FCFS:**
  - 1 hour time intervals

- **CRITERION 7:**
  - 1 hour time intervals
Simulation Results

Impact of prioritization criteria on the network stability (SCENARIO 1)

Results:

- The undesirable network effects (delay propagation and overloads at airport not impacted by external Disturbances) are not better absorbed when applying specific criteria instead of FCFS.
- However, slight improvements are detected at airport level in specific timeframes.

Conclusions:

- None of the selected prioritization criteria improves the situation at global level with respect to the FCFS basis;
- Further research to analyse if any of the criteria could improve problematic hours at local level;
- This would require the local switch on/off of criteria at specific times and the study of which timeframe is the most efficient in terms of reducing undesirable effects.
Simulation Results

Relation between network stability and equity (SCENARIO 2)

Results:

- The **best network performance results** were obtained with **alpha closer to one**;
  - Flight priority in two parts: \( Pr = \alpha \text{(airlines criteria)} + (1-\alpha) \text{(network criteria)} \)

- What is good for airlines might be also good for the network (since airline performance relies on network performance);
- Note that for designing this scenario, there was not direct input form airlines;

Conclusion:

- Need of further exploring if what is good for one particular airline or for a set of airlines operating at the airport where a local problem arise, might be good for the whole network;
Simulation Results

Airlines interests as a black box (SCENARIO 3)

- The approach is just the same as for the Scenario 2

\[ Pr = \alpha \text{ (random function between 1 and 0) } + (1- \alpha) \text{ (network criteria)} \]

Results:

- The values of the Indicators showed that giving less weight to network-driven prioritisation criteria provided better network performance;

Conclusions

- As in Scenario 2, values for \( \alpha \) closer to 1 give better results
- There were very different performance responses between time intervals suggesting that for optimising the network management the application of criteria should be restricted to specific airports at specific timeframes;
Simulation Results

Network critical load analysis (SCENARIO 4)

Results:

- For all the Performance Indicators and CRITERIA analysed, the situation became unstable in the peak hours of the day;
- All the prioritization criteria under analysis presented worse results than the ones obtained with FCFS basis, showing high delay queues and calling for flight regulation in most cases;
- An improvement on average delays was observed at the end of the simulation exercise for 1,33 CURRENT TRAFFIC and 1,66 CURRENT TRAFFIC load levels giving signs of potential system recovery;

Conclusions:

- the application of certain prioritization criteria for long periods of time improves the negative effects of the network and absorbs the systems delays;
Simulation Results

Most Capable Best Served (SCENARIO 5)

Approach:
- How to reward operationally investing airlines in the transition period where ground systems are not prepared to give them any technical advantage?

Facts:
- Most Capable: 4 Exercises, with different percentages of capable flights.
- Best Served: These flights will be given priority on departure

Conclusions:
- The number of capable flights for all the exercises is between 10%-35% so giving priority to such a percentage of flights (labelled as capable on the tool) does not represent an improvement to the global situation;
- As for the airlines interests, the results could be interpreted the other way around:
  - To give precedence to capable flights, which means an advantage at local level for the airline, has not meaningful harmful effect for the global network behaviour.
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